



PCT/GB 2003 / 0 0 3 8 2 7

PCT/GB 2003 / 0 0 3 8 2 7

INVESTOR IN PEOPLE

The Patent Office  
Concept House  
Cardiff Road  
Newport  
South Wales  
NP10 8QQ

**PRIORITY  
DOCUMENT**  
SUBMITTED OR TRANSMITTED IN  
COMPLIANCE WITH RULE 17.1(a) OR (b)

REC'D 23 OCT 2003

WIPO PCT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

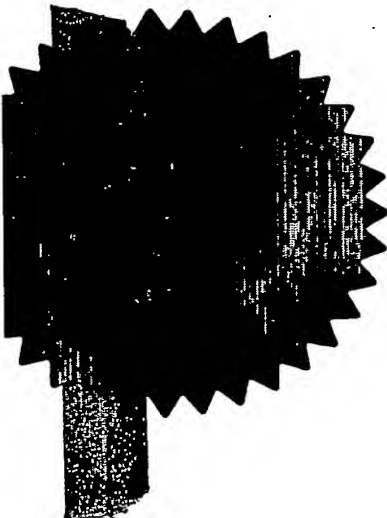
Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

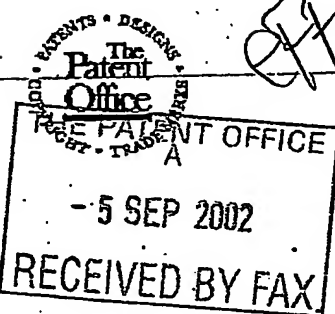
*Stephen Hordley*

Dated 25 September 2003

Best Available Copy



## Patents Form 1/77

Patents Act 1977  
(Rule 16)05SEP02 E7 146-1 001091  
P01/7700 0:00-02 0645.6

## Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

The Patent Office

Cardiff Road  
Newport  
South Wales  
NP10 8QQ

1. Your reference

AA 1610 GB

2. Patent application number

(The Patent Office will fill in this part)

05 SEP 2002

0220645.6

3. Full name, address and postcode of the or of each applicant (underline all surnames)

00536268007

Patents ADP number (if you know it)

JOHNSON MATTHEY PUBLIC LIMITED COMPANY  
2-4 COCKSPUR STREET  
TRAFALGAR SQUARE  
LONDON SW1 5BQ

If the applicant is a corporate body, give the country/state of its incorporation

GB

4. Title of the invention

EXHAUST SYSTEM FOR A LEAN BURN IC ENGINE

5. Name of your agent (if you have one)

ANDREW DOMINIC NUNN

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

08083206001

Patents ADP number (if you know it)

JOHNSON MATTHEY TECHNOLOGY CENTRE  
BLOUNTS COURT  
SONNING COMMON  
READING RG4 9NH

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number

Country

Priority application number  
(if you know it)Date of filing  
(day / month / year)

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application

Date of filing  
(day / month / year)

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

YES

- a) any applicants named in part 3 is not an inventor, or
  - b) there is an inventor who is not named as an applicant, or
  - c) any named applicant is a corporate body.
- See note (d)

## Patents Form 1/77

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form

Description 16 /

Claim(s) 4 /

Abstract 1 /

Drawing(s) 3 only /

10. If you are also filing any of the following, state how many against each item.

Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

ONE /

Request for substantive examination. (Patents Form 10/77)

Any other documents (please specify)

11.

I/We request the grant of a patent on the basis of this application

Signature

A D NUNN

Date 5/9/02

12. Name and daytime telephone number of person to contact in the United Kingdom

MRS F B STRANGE 0118 924 2125

## Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

## Notes

- If you need help to fill in this form or you have any questions, please contact the Patent Office on 08459 500505.
- Write your answers in capital letters using black ink or you may type them.
- If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.
- If you have answered 'Yes' Patents Form 7/77 will need to be filed.
- Once you have filled in the form you must remember to sign and date it.
- For details of the fee and ways to pay please contact the Patent Office.

DUPLICATE

AA 1610

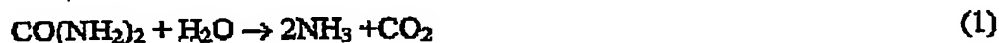
EXHAUST SYSTEM FOR LEAN BURN IC ENGINES

The present invention relates to an exhaust system for a lean-burn internal combustion engine, which exhaust system comprising a NO<sub>x</sub> trap and a catalyst for catalysing the reduction of NO<sub>x</sub> with a NO<sub>x</sub> specific reactant, e.g. NH<sub>3</sub>.

By "NO<sub>x</sub> specific reactant" herein, we mean a reducing agent that, in most conditions, preferentially reduces NO<sub>x</sub> over other components of a gaseous mixture. Examples of NO<sub>x</sub> specific reactants include nitrogenous compounds such as nitrogen hydrides, e.g. ammonia (NH<sub>3</sub>) or hydrazine, or an NH<sub>3</sub> precursor.

By "NH<sub>3</sub> precursor" we mean one or more compounds from which NH<sub>3</sub> can be derived, e.g. by hydrolysis. These include urea (CO(NH<sub>2</sub>)<sub>2</sub>) as an aqueous solution or as a solid or ammonium carbamate (NH<sub>2</sub>COONH<sub>4</sub>). If the urea is used as an aqueous solution, a eutectic mixture, e.g. a 32.5% NH<sub>3</sub> (aq), is preferred. Additives can be included in the aqueous solutions to reduce the crystallisation temperature.

Urea hydrolyses at temperatures above 160°C according to equation (1) to liberate NH<sub>3</sub> itself. It also thermally decomposes at this temperature and above according to equations (2) and (3) resulting in reduction of NO<sub>x</sub>.



The NH<sub>3</sub> can be in anhydrous form or as an aqueous solution, for example.

The application of NH<sub>3</sub> SCR technology to treat NO<sub>x</sub> emissions from IC engines, particularly lean-burn IC engines, is well known. Several chemical reactions occur in the NH<sub>3</sub> SCR system, all of which represent desirable reactions which reduce NO<sub>x</sub> to elemental nitrogen. The dominant reaction mechanism is represented in equation (4).



Competing, non-selective reactions with oxygen can produce secondary emissions or may unproductively consume  $\text{NH}_3$ . One such non-selective reaction is the complete oxidation of  $\text{NH}_3$ , represented in equation (5).



Presently, urea is the preferred source of  $\text{NH}_3$  for mobile applications because it is less toxic than  $\text{NH}_3$ , it is easy to transport and handle, is inexpensive and commonly available.

Early methods of using urea as a source of  $\text{NH}_3$  in exhaust systems involved injecting urea directly into the exhaust gas, optionally over an in-line hydrolysis catalyst (see EP-A-0487886 (incorporated herein by reference)). However, not all urea is hydrolysed in such arrangements, particularly at lower temperatures.

Incomplete hydrolysis of urea can lead to increased PM emissions on tests for meeting the relevant emission test cycle because partially hydrolysed urea solids or droplets will be trapped by the filter paper used in the legislative test for PM and counted as PM mass. Furthermore, the release of certain products of incomplete urea hydrolysis, such as cyanuric acid, is environmentally undesirable. Another method is to use a pre-injection hydrolysis reactor (see US-A-5,968,464 (incorporated herein by reference)) held at a temperature above that at which urea hydrolyses.

It will be appreciated that at lower temperatures, below about  $100\text{--}200^\circ\text{C}$ ,  $\text{NH}_3$  can also react with  $\text{NO}_2$  to produce explosive ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ) according to equation (6):



For the avoidance of doubt, the present invention does not embrace such reactions or the promotion of conditions which bring them about. For example, the reaction can be avoided by ensuring that the temperature does not fall below about  $200^\circ\text{C}$  or by supplying into a gas stream less than the precise amount of  $\text{NH}_3$  necessary for the stoichiometric reaction with  $\text{NO}_x$  (1 to 1 mole ratio). For cold start applications, measures to prevent water from contacting the catalyst can be adopted. These can include disposing a water trap, e.g. a zeolite, upstream of the catalyst.

to reduce the amount of water vapour contacting the catalyst until it is heated sufficiently. A water trap can also be positioned downstream of the catalyst, to prevent atmospheric humid air from travelling up the exhaust pipe. An electric heater can also be employed to drive off moisture from the catalyst pre-cold start. Such arrangements are described in our EP 0747581, (incorporated herein by reference).

In order to meet existing and future emission legislation, generally a vehicular exhaust system includes one or more components, such as catalysts. One of the legislated exhaust gas components is  $\text{NO}_x$ . During normal operation, the exhaust gas produced by a lean-burn internal combustion engine, for example, includes an excess of oxygen and oxidising species. It is very difficult to reduce  $\text{NO}_x$  to  $\text{N}_2$  in an oxidising or lean atmosphere. In order to treat  $\text{NO}_x$  in lean exhaust gases, a component has been developed that absorbs  $\text{NO}_x$  during normal lean-burn operation of the engine. This component is commonly called a  $\text{NO}_x$ -trap and generally it includes: (i) an oxidation catalyst (e.g. platinum) to oxidise  $\text{NO}$  in the exhaust gas to  $\text{NO}_2$  in the oxidising atmosphere; (ii) a  $\text{NO}_x$  storage component to store the  $\text{NO}_2$  e.g. as the nitrate. The  $\text{NO}_x$  storage component is generally a basic compound of an alkali metal or an alkaline-earth, such as barium oxide; and (iii) a reduction catalyst, such as rhodium. It is possible, however, to use a  $\text{NO}_x$  trap formulation in certain circumstances which comprises only the  $\text{NO}_x$  storage component, or the  $\text{NO}_x$  storage component and one or other of the oxidation and reduction catalyst.

Intermittently, the engine is run rich, e.g. by adjusting the moment of fuel injection into one or more cylinders, or by injecting a reducing agent, e.g. a hydrocarbon fuel, into the exhaust gas, in order to remove the stored  $\text{NO}_x$  and reduce it to  $\text{N}_2$ . This also regenerates the absorber for another store-regenerate cycle.

Another approach for removing  $\text{NO}_x$  from a gas stream is by selective catalytic reduction (SCR), which comprises adding e.g.  $\text{NH}_3$  to the gas and passing the mixture over a catalyst effective to react the  $\text{NO}_x$  and  $\text{NH}_3$  to nitrogen. Another approach is described in our WO 00/21647 (incorporated herein by reference) wherein  $\text{NO}_x$  from a diesel engine exhaust gas is removed by absorbing it in a solid absorbent. The absorbent is regenerated by the action of a  $\text{NO}_x$ -specific reactant.

Either such process requires careful control to avoid over- or under-supply of e.g.  $\text{NH}_3$ ,

leading respectively to emission of  $\text{NH}_3$  or  $\text{NO}_x$ .  $\text{NH}_3$  is an irritant and has an unpleasant odour and, accordingly, it is undesirable to slip  $\text{NH}_3$  to atmosphere. In practice this would mean positioning an oxidation "clean-up" catalyst downstream of the SCR catalyst or  $\text{NO}_x$ -trap to oxidise slipped  $\text{NH}_3$  to  $\text{NO}_x$ . Therefore, slipping  $\text{NO}_x$  *per se*, by providing inadequate levels of  $\text{NH}_3$ , or  $\text{NH}_3$  would have the effect of reducing the overall effectiveness of the exhaust system to limit  $\text{NO}_x$  emissions.

One problem associated with  $\text{NH}_3$  SCR technology is to maintain good  $\text{NO}_x$  conversion when the exhaust gas temperature is relatively low, e.g. during extended idling or following cold-start.  $\text{NO}_x$  conversion can be achieved using  $\text{NH}_3$  at temperatures as low as  $150^\circ\text{C}$  using Pt-based catalysts, but the preferred delivery form of  $\text{NH}_3$ , aqueous urea solution, does not decompose significantly below  $200^\circ\text{C}$ . Pt-based catalysts generate nitrous oxide (NO) according to equation (5) at above about  $225^\circ\text{C}$ .

Changes in engine test cycles have been introduced in the present Euro III standard and will govern Euro IV type approval of new vehicles. In particular, the new test cycles include the European Stationary Cycle (ESC); the European Transient Cycle (ETC); and a test for smoke opacity on the European Load Response (ELR) test. These cycles and tests include significant periods at low temperature. To attain type approval, a new vehicle will have to pass both the ETC and ESC/ELR tests.

It is stated in our WO 00/21647 that "If the [ $\text{NH}_3$  SCR] catalyst system is associated with the [ $\text{NO}_x$ ] absorbent, that is the absorber is 'catalysed', the catalytic material may be for example co-precipitated or co-impregnated or co-deposited with  $\text{NO}_x$  absorbent or present as one or more sandwiched layers or as fine (e.g. 10-500 microns) particles on or in a layer of absorbent or among particles of absorbent".

Elsewhere in WO 00/21647 we state that the point of injection of a  $\text{NO}_x$  specific reactant can be downstream of the filter, i.e. upstream of the  $\text{NO}_x$  absorbent and "in this event the temperature is typically in the range  $150$ - $300^\circ\text{C}$ ".

We have looked at putting barium (a  $\text{NO}_x$  absorbent) on a cerium and iron-containing SCR catalyst, and the SCR function was significantly reduced, although the ability of the composition to absorb and desorb  $\text{NO}_x$  was unimpaired. In our PCT/GB02/00784 we

demonstrate the principle of using  $\text{NH}_3$  (or urea) injection over a  $\text{NO}_x$  trap catalyst to reduce stored  $\text{NO}_x$  during lean running conditions. This arrangement is particularly useful for diesel applications. In PCT/GB02/00784 we state: "Whichever [ $\text{NO}_x$  storage] compounds are used, there may be present also one or more catalytic agents, such as precious metals, effective to promote reactions of  $\text{NO}_x$ -specific reactant [including  $\text{NH}_3$ ] with nitroxy salt. Such catalysts are also known as SCR catalysts and can include iron/zeolite or  $\text{V}_2\text{O}_5/\text{TiO}_2$ . Where the  $\text{NO}_x$  absorbent and SCR catalyst are associated, in one embodiment they are segregated. By 'segregated' we mean that they should, at least, be supported on separate supports and can therefore be disposed in separate layers above and/or below the other component or in the same layer. Alternatively, they can be coated on distinct areas of the same substrate 'brick' or on separate substrates disposed within the same system."

We have now found that it is possible to use a  $\text{NO}_x$  absorbent disposed downstream of a SCR catalyst to prevent  $\text{NH}_3$  slip from an SCR catalyst, and  $\text{NO}_x$  and  $\text{NH}_3$  slip from the system as a whole. We have also found that it is possible to regenerate a  $\text{NO}_x$  absorbent in a manner set out in our PCT/GB02/00784 by intentionally slipping a controlled amount of  $\text{NH}_3$  past an SCR catalyst when the catalyst is above a pre-determined temperature.

According to a first aspect, the invention provides an exhaust system for a lean-burn internal combustion engine, which system comprising a nitrogen oxide ( $\text{NO}_x$ ) absorbent, a catalyst for catalysing the selective catalytic reduction (SCR) of  $\text{NO}_x$  with a  $\text{NO}_x$  specific reactant, first means for introducing a  $\text{NO}_x$  specific reactant or a precursor thereof into an exhaust gas upstream of the SCR catalyst and means for controlling the introduction of the  $\text{NO}_x$  specific reactant or precursor thereof into the exhaust gas via the first introducing means, wherein the SCR catalyst is disposed upstream of the  $\text{NO}_x$  absorbent and optionally with the  $\text{NO}_x$  absorbent, characterised in that the control means is arranged to supply the  $\text{NO}_x$  specific reactant or the precursor thereof to the first introducing means only when the SCR catalyst is above a first pre-determined temperature, whereby exhaustion of  $\text{NO}_x$  specific reactant to atmosphere is substantially prevented.

The  $\text{NO}_x$  absorbent is supported on a first substrate and the SCR catalyst can be supported on a second substrate.



Desirably, the control means is arranged also to interrupt the supply of the NO<sub>x</sub> specific reactant or the precursor thereof to the first introducing means when the SCR catalyst is above a second pre-determined temperature.

5 According to one embodiment, the exhaust system comprises a second means for introducing the NO<sub>x</sub> specific reactant or the precursor thereof, which second introducing means is disposed upstream of the NO<sub>x</sub> absorbent and downstream of the SCR catalyst. Desirably, the control means is arranged also to supply the NO<sub>x</sub> specific reactant or the precursor thereof to the second introducing means only when the NO<sub>x</sub> absorbent is above a third pre-determined  
10 temperature and, optionally, to interrupt the supply of the NO<sub>x</sub> specific reactant or the precursor thereof to the second introducing means when the NO<sub>x</sub> absorbent is above a fourth pre-determined temperature.

We have observed that when a NO<sub>x</sub> specific reactant is introduced into an exhaust gas  
15 upstream of the SCR catalyst, certain reactants, such as NH<sub>3</sub>, can become adsorbed to the SCR catalyst. Suitable control methods can make allowances for this and in certain arrangements the adsorption phenomenon can be useful, e.g. for supplying low levels of NO<sub>x</sub> specific reactant to the SCR catalyst below the SCR catalyst light off temperature to effect NO<sub>x</sub> conversion. However, the adsorption can complicate control of supply of NO<sub>x</sub> specific reactant to the  
20 downstream NO<sub>x</sub> absorbent to effect the process described in our PCT/GB02/00784. Accordingly, in one embodiment, a second, separate NO<sub>x</sub> specific reactant introducing means is provided downstream of the SCR catalyst and the NO<sub>x</sub> specific reactant or precursor thereof is introduced via only this second introducing means when the SCR catalyst is below its light off temperature. ("Light off" is the temperature of a catalyst at which 50% conversion of a particular  
25 reaction is achieved.)

The first and second pre-determined temperatures will depend on the nature of the SCR catalyst (see below), and on other factors such as the composition and temperature range of the exhaust gases to be treated. However, generally the first predetermined temperature will be in the  
30 range from 100-600°C, preferably 150-500°C and most preferably 200-450°C and the second pre-determined temperature will be from 450-900°C, preferably 550-800°C and most preferably 650-700°C.

Like the SCR catalyst, the third and fourth pre-determined temperatures will depend on the nature of the NO<sub>x</sub> absorbent (see below), and on other factors such as the composition and temperature range of the exhaust gases to be treated. However, generally the third pre-determined temperature will be from 75-200°C, preferably 100-175°C and most preferably 125-600°C and the fourth pre-determined temperature will be from 350-600°C, preferably 400-550°C and most preferably 450-500°C.

In another embodiment, the first pre-determined temperature can be the same as the third pre-determined temperature.

According to another embodiment, the exhaust system comprises a second SCR catalyst disposed downstream of the NO<sub>x</sub> absorbent.

Control of the system is effected by the control means. In preferred embodiments, the control means receives input from sensors positioned at appropriate points in the exhaust system to detect certain conditions therein. These can include the temperature of the NO<sub>x</sub> absorbent and/or the SCR catalyst, and the NO<sub>x</sub> composition of the exhaust gas. In order to control the system to prevent slip of NO<sub>x</sub> specific reactant, suitable sensors can be used. These can be positioned downstream of the SCR catalyst and/or downstream of the NO<sub>x</sub> absorbent. In addition, or in the alternative, the control means can control the system in response to pre-determined settings in an engine speed/load map.

Supply of NO<sub>x</sub> specific reactant can be continuous, semi-continuous, or periodic. In any case, the control means can be arranged to supply the NO<sub>x</sub> specific reactant or the precursor thereof intermittently at "spike" concentration, which can be useful for example in the method of regenerating the NO<sub>x</sub> absorbent. Where supply of the NO<sub>x</sub> specific reactant or precursor thereof is periodic, each such period between supply events can be selected from between 1 second and 10 minutes.

According to a further aspect, the invention provides a lean-burn internal combustion engine including an exhaust system according to any preceding claim. According to one embodiment, the lean-burn engine is a diesel engine or a gasoline engine. We particularly prefer engines that can be run on fuel of less than 10 ppm sulfur.

According to a further aspect, the invention provides a process for treating  $\text{NO}_x$  in an exhaust gas from a lean-burn internal combustion engine, which engine including an exhaust system comprising a nitrogen oxide ( $\text{NO}_x$ ) absorbent and a catalyst for catalysing the selective catalytic reduction (SCR) of  $\text{NO}_x$  with a  $\text{NO}_x$  specific reactant wherein the SCR catalyst is disposed upstream of the  $\text{NO}_x$  absorbent and optionally with the  $\text{NO}_x$  absorbent, which process comprising, when the SCR catalyst is below a first pre-determined temperature, contacting the  $\text{NO}_x$  absorbent with insufficient  $\text{NO}_x$  specific reactant to completely reduce the total  $\text{NO}_x$  stored on the  $\text{NO}_x$  absorbent, thereby to regenerate it, and, when the SCR catalyst is above said first pre-determined temperature, contacting it with sufficient  $\text{NO}_x$  specific reactant to reduce  $\text{NO}_x$  in the exhaust gas to  $\text{N}_2$ , whereby exhaustion of  $\text{NO}_x$  specific reactant to atmosphere is substantially prevented.

In one embodiment of the process, the  $\text{NO}_x$  specific reactant for contacting the  $\text{NO}_x$  absorbent when the SCR catalyst is below the first pre-determined temperature does not contact said catalyst, for the reasons relating to adsorption of the  $\text{NO}_x$  specific reactant to the SCR catalyst as explained above. That is, the  $\text{NO}_x$  specific reactant can be introduced into the exhaust gas at a point downstream of the SCR catalyst.

In another embodiment, when said SCR catalyst is above said first pre-determined temperature, sufficient  $\text{NO}_x$  specific reactant contacts the SCR catalyst to reduce  $\text{NO}_x$  in the exhaust gas to  $\text{N}_2$  and slips past the SCR catalyst to contact the  $\text{NO}_x$  absorbent thereby to reduce stored  $\text{NO}_x$ , which process is controlled so that the slipped  $\text{NO}_x$  specific reactant is insufficient to completely reduce the total  $\text{NO}_x$  stored. In this embodiment, the  $\text{NO}_x$  specific reactant can be introduced into the exhaust gas upstream of the SCR catalyst and optionally downstream thereof also, as desired.

In the process according to the invention, the first pre-determined temperature can be from 100-600°C, preferably 150-500°C and most preferably 200-450°C, for example.

Process features for controlling  $\text{NO}_x$  absorbent regeneration may be similar to those set out in our PCT/GB02/00784 and can include the features that at the end of regeneration, the  $\text{NO}_x$  absorbent contains 5 to 50% of the content of  $\text{NO}_x$  present at the start of regeneration; that regeneration is started when the absorbent contains 5 to 50% of the  $\text{NO}_x$  content at which  $\text{NO}_x$  slip takes place; that regeneration is controlled to stop at one of the following points: when  $\text{NO}_x$

specific reactant is detected at a point part-way along the length of a substrate carrying the NO<sub>x</sub> absorbent; in a system having two substrates carrying the solid absorbent in series, when NO<sub>x</sub> specific reactant is detected at a point between the substrates; when a level of NO<sub>x</sub> content prescribed on the basis of pre-determined data in an engine speed/load map has been reached; when a level of NO<sub>x</sub> content established iteratively from an initial observation of NO<sub>x</sub> specific reactant slip has been reached; and that the NO<sub>x</sub> specific reactant is produced *in situ* from a precursor thereof, wherein the NO<sub>x</sub> specific reactant can be liberated from the precursor by a catalytic reaction.

10 The NO<sub>x</sub> absorbent and any catalyst are suitably supported on a ceramic or metal honeycomb or foam substrate, the ceramic comprising one or more of alumina, silica, titania, cordierite, ceria, zirconia, zeolite or other, generally oxidic, material or a mixture or mixed oxide of any two or more thereof. Silicon carbide is another possible substrate material. The honeycomb or foam substrate preferably carries a washcoat and, in one or more layers thereon,  
15 the active absorptive and/or catalytic material. The honeycomb has typically at least 50, for example 50-400, cells per square inch (cpsi), possibly more, e.g. up to 800 cpsi, or up to 1200 cpsi if composed structurally of metal. Generally the range 200-800 cpsi is preferred for the substrate comprising nitroxy salt or absorbent and any catalyst.

20 The NO<sub>x</sub> absorbent may be selected from compounds of alkali metals, alkaline earth metals, rare earth metals, such as lanthanides, and transition metals, capable of forming nitroxy salt (nitrates and/or nitrites) of adequate stability in absorbing conditions and of reacting with NO<sub>x</sub>-specific reactant in regenerating conditions. The "conditions" can include temperature of the gas and its redox state as expressed for example by its lambda; and/or adsorptive materials  
25 such as zeolites, carbons and high-area oxides.

Suitable alkali metals for use as NO<sub>x</sub> absorbents can be at least one of potassium, or caesium; alkaline earth metals can be at least one of magnesium, calcium, strontium and barium; and lanthanides can be at least one of lanthanum, praseodymium, neodymium and cerium.

30

Absorbent compounds may be present (before NO<sub>x</sub> absorption) as composite oxides, e.g. of alkaline earth metal and copper such as Ba-Cu-O or MnO<sub>2</sub>-BaCuO<sub>2</sub>, possibly with added Ce oxide, or Y-Ba-Cu-O and Y-Sr-Co-O. (The oxides are referred to for simplicity, but in practice

hydroxides, carbonates and carboxylates such as acetates are present, depending on the temperature and gas composition).

5 The NO<sub>x</sub> absorbent can be associated with one or more platinum group metals (PGM) in order to effect certain processes useful to the procedure of storing NO<sub>x</sub> thereon, or reducing released NO<sub>x</sub> to N<sub>2</sub>. Such PGMs can be platinum, palladium and rhodium. In one embodiment, the NO<sub>x</sub> trap PGM consists platinum alone, whereas in another embodiment it can include both platinum and rhodium.

10 The SCR catalysts for use in the present invention can be any known to the person skilled in the art, and, as mentioned above, choice of the SCR catalyst can depend on the conditions in which the catalyst will be required to work.

For example, Pt-based SCR catalysts can catalyse the reduction of NO<sub>x</sub> with NH<sub>3</sub> at 15 between about 175°C and about 250°C. Above 250°C the oxidation of NH<sub>3</sub> to NO predominates, thus losing its selectivity. Medium temperature vanadium-based catalysts e.g. V<sub>2</sub>O<sub>5</sub>/TiO<sub>2</sub> operates in the temperature range between about 260°C and about 450°C. Again beyond this higher temperature, selectivity is lost and NO is produced. If the exposure temperature of the V<sub>2</sub>O<sub>5</sub>/TiO<sub>2</sub> catalyst exceeds a certain level, the active, high surface area anatase phase of TiO<sub>2</sub> 20 irreversibly converts to rutile with a surface area of less than 10 m<sup>2</sup>/g. Normally this conversion takes place above about 550°C, but catalysts may include stabilisers to increase their thermal durability. Some V<sub>2</sub>O<sub>5</sub>/TiO<sub>2</sub> catalysts have been reported to be thermally stable up to about 700°C. In certain situations, it can be useful to include at least one of tungsten and molybdenum with base metal-containing SCR catalysts.

25

Zeolites can operate in the temperature range of about 350°C to about 600°C. Zeolites suitable for use in catalysts according to the present invention include ZSM-5, mordenite, gamma-zeolite or beta-zeolite. They can comprise at least one metal or be metallised with at least one metal, which metal can be selected from one or more of Cu, Ce, Fe or Pt, and they can 30 be ion-exchanged or impregnated.

Zeolites are characterised by their crystalline structure and SiO<sub>2</sub>:Al<sub>2</sub>O<sub>3</sub> ratio. For example, common mordenites have a ratio of about 10. When NO<sub>x</sub> is present in the exhaust gas, zeolite-based SCR catalysts do not oxidise NH<sub>3</sub> to NO<sub>x</sub>. Therefore, unlike Pt or V<sub>2</sub>O<sub>5</sub> catalysts,

its selectivity towards  $\text{NO}_x$  conversion continually increases with temperature. However, zeolite-based catalysts can have stability problems when exposed to high temperatures in the presence of water vapour. At exposure temperatures above  $600^\circ\text{C}$ , in a high water content process stream, zeolites tend to deactivate by de-alumination whereby  $\text{Al}^{3+}$  ion in the  $\text{SiO}_2\text{-Al}_2\text{O}_3$  framework migrates out of the structure. This leads to permanent deactivation and, in extreme cases, collapse of the crystalline structure.

Of course, zeolites are preferred where adsorption of  $\text{NH}_3$  on a catalyst is required, see WO 99/55446.

Non-zeolite supports for any of metal-based SCR catalysts can include at least one of alumina, titania, silica, silica-alumina, ceria, zirconia, or a mixture or a mixed oxide of any two or more thereof.

As defined herein a "solid absorbent", "absorbent" and "absorbent material", "storage component" are used interchangeably; By " $\text{NO}_x$  absorbent" herein we refer to the optionally supported alkali metal, alkaline earth metal, rare-earth metal or transition metal *per se*, i.e. without additional catalytic metal; By " $\text{NO}_x$  trap", we refer to a substrate comprising the  $\text{NO}_x$  absorbent and any additional catalytic material e.g. PGM.

The exhaust systems for the present invention are for IC engines and in particular to lean-burn IC engines. These can include gasoline lean-burn engines, such as gasoline direct injection (GDI) engines. It can also include diesel engines. In particular, diesel engines can include heavy-duty diesel engines (as defined in Europe by European Directives 88/77/EEC and 1999/96/EC). In the USA, heavy-duty vehicles are defined by gross vehicle weight rating (GVWR) 8,500 lbs in the US Federal jurisdiction and above 14,000 lbs in California (model year 1995 and later). The heavy-duty diesel category is subdivided into light heavy-duty diesel engines:  $<8,500 \text{ lbs} < \text{LHDDE} < 19,500 \text{ lbs}$  ( $14,000 \text{ lbs} < \text{LHDDE} < 19,500$  in California, 1995+); medium heavy-duty diesel engines:  $19,500 \text{ lbs} < \text{MHDDE} < 33,000 \text{ lbs}$ ; and heavy heavy-duty diesel engines (including urban buses):  $\text{HHDE} > 33,000 \text{ lbs}$ . Diesel engines can also be light-duty diesel engines as defined in Europe by European Directive 70/220/EEC, as amended by 93/59/EC and 98/69/EC. In the USA passenger vehicles, light light-duty trucks (LLDT), below 6000 lbs GVWR and heavy light-duty trucks (HLDT), above 6000 lbs are included in the light-duty diesel category.

In order that the invention may be more fully understood, the following embodiment and Examples are provided by way of illustration only and with reference to the accompanying drawings, in which:

Figure 1 is a schematic sectional view of an exhaust treatment system for lean-burn internal combustion engine;

Figure 2 is a graph comparing  $\text{NH}_3$  slip in an exhaust system comprising SCR catalysts alone with that in an exhaust system comprising SCR and  $\text{NO}_x$  trap catalysts; and

Figure 3 is a graph showing the gradual loss of  $\text{NO}_x$  conversion after  $\text{NH}_3$  is turned off in an exhaust system comprising SCR and  $\text{NO}_x$  trap catalysts.

Referring to Figure 1, the system illustrated consists of single "can" 10, which is connected at 12 to the exhaust from a diesel engine (not shown) fuelled with diesel oil of under 10 ppm sulfur content. At the inlet end of can 10 is catalyst 14, which is a low temperature light-off oxidation catalyst supported on a 400 cells/ $\text{m}^2$  ceramic honeycomb monolith. Catalyst 14 is designed to be capable of meeting emission regulations in relation to CO and HC for the engine and vehicle and also converts the NO in the starting gas to  $\text{NO}_2$  at temperatures of up to 400°C at an efficiency of up to 70% or more.

The gas leaving catalyst 14 passes into soot filter 16, which is of the ceramic wall flow type and collects PM over 50nm. The  $\text{NO}_2$  and surplus oxygen in the gas oxidise the soot at temperatures around 250°C as described in EP-A-341832. The gas leaving filter 16 is passed over sparging spray injector 18, from which it receives intermittent supplies of  $\text{NH}_3$  or  $\text{NH}_3$  precursor via line 20 from high-pressure pump 22 under the control of computer 24. The gas leaving injector 18 passes into an SCR catalyst 30 comprising  $\text{V}_2\text{O}_5/\text{TiO}_2$ . Computer 24 receives data on engine running time and fuel used, on inlet gas temperature and composition and also, from sensor 26, on any slipped  $\text{NO}_x$  or  $\text{NH}_3$ . It is programmed in particular to recalculate the  $\text{NH}_3$  feed time to a shorter period and/or at a lower rate if  $\text{NH}_3$  is detected in gas leaving  $\text{NO}_x$  trap 28.

To facilitate replacement of NO<sub>x</sub> trap 28, the can portion containing it may be linked to the main upper and lower portion of can 10 by flanges (not shown). If provision for SO<sub>x</sub> absorption is to be made, bed 28 may be in two parts, one upstream of the other, the upstream part being the SO<sub>x</sub> absorber. When the SO<sub>x</sub> -absorbing part is due for replacement, it can be replaced by a fresh SO<sub>x</sub> absorber and the can portion re-inserted with the unreplaced NO<sub>x</sub> trap in the upstream position.

In the operation of the system two phases alternate. In the absorption phase the gas contains no NH<sub>3</sub> and the NO<sub>x</sub> content of the absorber slowly increases as the NO<sub>x</sub> reacts with the absorbent to give solid nitroxy salt. The absorption phase can occur when the SCR catalyst is below its light-off temperature for catalysing the reaction of NH<sub>3</sub> and NO<sub>x</sub>, or when NO<sub>x</sub> not converted over the SCR catalyst when the SCR catalyst is above said light-off temperature is present in the exhaust gas leaving the SCR catalyst. At the end of this phase the regeneration phase takes place, in which NH<sub>3</sub> is injected until part, suitably 50-90%, or possibly 5-50%, of the nitroxy salt has been reacted. During regeneration the system slips substantially no NH<sub>3</sub> downstream of NO<sub>x</sub> trap 28.

The regeneration phase can occur when the SCR catalyst is below or above its light-off temperature for catalysing the reaction of NH<sub>3</sub> and NO<sub>x</sub>. When below SCR catalyst light-off temperature, the NH<sub>3</sub> or NH<sub>3</sub> precursor is metered so that substantially all of the NH<sub>3</sub> is consumed by the stored NO<sub>x</sub>. When the SCR catalyst has lit off, NH<sub>3</sub> or NH<sub>3</sub> precursor is metered so that an above stoichiometric amount of NH<sub>3</sub> is present relative to NO<sub>x</sub> over the SCR catalyst so that the SCR catalyst slips sufficient NH<sub>3</sub> to regenerate the NO<sub>x</sub> trap. Stopping NH<sub>3</sub> slip past the SCR catalyst ends the regeneration phase, so that the absorption phase re-starts with absorption of residual NO<sub>x</sub> from its end-level attained in the regeneration phase. Alternatively, no provision for intentional NH<sub>3</sub> slip is made, and the NO<sub>x</sub> trap is regenerated "passively" by NH<sub>3</sub> slipped from the SCR catalyst. If the regeneration phase were continued for longer, for example up to complete decomposition of the nitroxy salt, the NH<sub>3</sub> content of the gas leaving absorber 28 would rise to its level at the start of regeneration, thus emitting NH<sub>3</sub> to atmosphere unless a clean-up catalyst were provided as in conventional continuous SCR.

#### Example



A cordierite monolith (5.66 inch diameter, 6 inch long, 400 cells per square inch with 6 thousandths of an inch (0.15 mm) thick walls) was coated with a washcoat consisting of gamma alumina (surface area  $120 \text{ m}^2 \text{ g}^{-1}$ ) in water made by slurring sufficient solid in de-ionised water to give a solids content of 45%. The slurry was poured onto the face and down the channels of the ceramic monolith. Excess slurry was removed from the channels by compressed air. The water was then removed from the washcoat by drying in a hot air flow ( $150^\circ\text{C}$ ). The dry coated monolith was then calcined at  $500^\circ\text{C}$  for an hour. The total washcoat loading on the coated monolith was  $2.5 \text{ g in}^{-3}$ . The coated monolith was then immersed in a platinum tetra-ammine solution for five minutes, removed, and excess solution removed by suction. The monolith was then dried in a hot air flow ( $150^\circ\text{C}$ ) and calcined at  $500^\circ\text{C}$  for an hour. The concentration of solution was chosen to give a platinum loading of  $100 \text{ g ft}^{-3}$  was achieved on the monolith. Next the monolith was impregnated with an aqueous barium acetate solution. The monolith was immersed in the solution for five minutes, removed, and excess solution removed by suction. The monolith was dried in a hot air flow ( $150^\circ\text{C}$ ) and calcined at  $500^\circ\text{C}$  for an hour. The concentration of solution was chosen such that a final barium loading of  $800 \text{ g ft}^{-3}$  was achieved on the monolith.

Using analogous methods, SCR catalysts were prepared (on 5.66 inch diameter, 6 inch long, 400 cells per square inch with  $6/1000^{\text{th}}$  inch (0.15 mm) thick walls), a commercially available  $\text{V}_2\text{O}_5/\text{TiO}_2$  catalyst available from Johnson Matthey plc.

The final monoliths were mounted in a stainless steel can using standard procedures, and fitted in the exhaust gas system of 2.2 litre, 4 cylinder turbo-charged diesel engine. The engine was coupled to a dynamometer in the conventional manner. The engine and dynamometer were computer controlled to allow a range of different engine operating conditions to be selected. Exhaust emissions of HC, CO,  $\text{NO}_x$ ,  $\text{O}_2$ , and  $\text{CO}_2$  pre- and post-catalyst were measured with commercial gas analysers in the conventional way.  $\text{NH}_3$  was measured using a tuned infra-red laser (AltOptronic), and  $\text{N}_2\text{O}$  was measured with a Unor (Germany) Instrument.

The engine was operated at 1200 rpm with a dynamometer load of 44 Nm, that resulted in a catalyst inlet exhaust gas temperature of  $210^\circ\text{C}$ . The catalyst inlet  $\text{NO}_x$  concentration was 120 ppm, and the engine was run steadily at this condition.  $\text{NH}_3$  gas was injected into the exhaust upstream of the catalyst in a 10 minute long pulse, before being turned off for a further 10

minutes. This alternation was continued 5 times. The  $\text{NH}_3$  gas level during the injection period was 120 ppm.

The experiment was conducted with two SCR catalysts alone in the exhaust as a baseline, and repeated with the  $\text{NO}_x$  trapping formulation behind the two SCR catalysts.

*Baseline tests:*

At this temperature/flow-rate/ $\text{NH}_3$  injection level, a significant amount of  $\text{NH}_3$  slip is possible from the SCR catalysts. This was desired in order to let  $\text{NH}_3$  reaching the  $\text{NO}_x$  trapping catalyst (when present) in order to effect the method described in PCT/GB02/00784 (the entire contents of which is incorporated herein by reference).

$\text{NH}_3$  slip gradually increased during the duration of the injection, it is believed, due to  $\text{NH}_3$  storage within the SCR catalysts. After 10 minutes of injection, 53 ppm  $\text{NH}_3$  slip occurred (shown Figure 1 for a typical 10 minute injection cycle). It was noted that with a period of > 10 minutes for  $\text{NH}_3$  injection, more  $\text{NH}_3$  slip occurred until a steady slip of 73 ppm  $\text{NH}_3$  was reached.  $\text{NO}_x$  conversion due to the SCR reaction was 20% at these operating conditions.

*Combined SCR and  $\text{NO}_x$  trapping catalyst tests:*

When the  $\text{NO}_x$  trapping catalyst is present in the exhaust, significantly lower  $\text{NH}_3$  slip occurs (see Figure 2), with a maximum of 20 ppm  $\text{NH}_3$  slip occurring after 10 minutes of  $\text{NH}_3$  injection. This indicates that the  $\text{NO}_x$  trapping catalyst can be used to prevent  $\text{NH}_3$  slip in an SCR system.

Further, as demonstrated in PCT/GB02/00784, this  $\text{NO}_x$  trap formulation can store  $\text{NO}_x$  at 210°C, and regenerate when exposed to  $\text{NH}_3$ . In the current example, 80% of the engine out  $\text{NO}_x$  is slipping through the SCR catalysts, as they are not active enough for the SCR reaction under these conditions. Some of this  $\text{NO}_x$  can be stored on the  $\text{NO}_x$  trapping catalyst, and this  $\text{NO}_x$  can be regenerated with the  $\text{NH}_3$  slip.

Figure 3 shows the  $\text{NO}_x$  conversion after  $\text{NH}_3$  injection. Clearly, when  $\text{NH}_3$  is turned off, there is a gradual decrease in  $\text{NO}_x$  conversion caused by a combination of  $\text{NO}_x$  storage and, we

believe, SCR reaction with stored  $\text{NH}_3$  as we describe in GB 0206888.0 (incorporated herein by reference). This effect was repeated multiple times.

**CLAIMS:**

1. An exhaust system for a lean-burn internal combustion engine, which system comprising a nitrogen oxide ( $\text{NO}_x$ ) absorbent, a catalyst for catalysing the selective catalytic reduction (SCR) of  $\text{NO}_x$  with a  $\text{NO}_x$  specific reactant, first means for introducing a  $\text{NO}_x$  specific reactant or a precursor thereof into an exhaust gas upstream of the SCR catalyst and means for controlling the introduction of the  $\text{NO}_x$  specific reactant or precursor thereof into the exhaust gas via the first introducing means, wherein the SCR catalyst is disposed upstream of the  $\text{NO}_x$  absorbent and optionally with the  $\text{NO}_x$  absorbent, characterised in that the control means is arranged to supply the  $\text{NO}_x$  specific reactant or the precursor thereof to the first introducing means only when the SCR catalyst is above a first pre-determined temperature, whereby exhaustion of  $\text{NO}_x$  specific reactant to atmosphere is substantially prevented.
2. An exhaust system according to claim 1, wherein the control means is arranged to interrupt the supply of the  $\text{NO}_x$  specific reactant or the precursor thereof to the first introducing means when the SCR catalyst is above a second pre-determined temperature.
3. An exhaust system according to claim 1 or 2, comprising a second means for introducing the  $\text{NO}_x$  specific reactant or the precursor thereof, which second introducing means is disposed upstream of the  $\text{NO}_x$  absorbent and downstream of the SCR catalyst.
4. An exhaust system according to claim 3, wherein the control means is arranged to supply the  $\text{NO}_x$  specific reactant or the precursor thereof to the second introducing means only when the  $\text{NO}_x$  absorbent is above a third pre-determined temperature.
5. An exhaust system according to claim 4, wherein the control means is arranged to interrupt the supply of the  $\text{NO}_x$  specific reactant or the precursor thereof to the second introducing means when the  $\text{NO}_x$  absorbent is above a fourth pre-determined temperature.
6. An exhaust system according to any preceding claim, wherein the first pre-determined temperature is from 100-600°C, preferably 150-500°C and most preferably 200-450°C.
7. An exhaust system according to claim 2, wherein the second pre-determined temperature is from 450-900°C, preferably 550-800°C and most preferably 650-700°C.

8. An exhaust system according to claim 4, wherein the third pre-determined temperature is from 75-200°C, preferably 100-175°C and most preferably 125-600°C.
- 5 9. An exhaust system according to any claim 8, wherein the first pre-determined temperature is the same as the third pre-determined temperature.
- 10 10. An exhaust system according to claim 5, wherein the fourth pre-determined temperature is from 350-600°C, preferably 400-550°C and most preferably 450-500°C.
- 10 11. An exhaust system according to any preceding claim, further comprising a second SCR catalyst disposed downstream of the NO<sub>x</sub> absorbent.
- 15 12. An exhaust system according to any preceding claim, including at least one sensor for detecting a concentration of the NO<sub>x</sub> specific reactant or the precursor thereof in the exhaust gas positioned downstream of the SCR catalyst.
- 20 13. An exhaust system according to any preceding claim, including at least one sensor for detecting a concentration of the NO<sub>x</sub> specific reactant or the precursor thereof in the exhaust gas positioned downstream of the NO<sub>x</sub> absorbent.
- 25 14. An exhaust system according to claim 12 or 13, wherein the control means regulates the supply of the NO<sub>x</sub> specific reactant or the precursor thereof in response to the detected concentration of the NO<sub>x</sub> specific reactant or the precursor thereof in the exhaust gas, thereby to reduce slip of the NO<sub>x</sub> specific reactant or the precursor thereof.
- 30 15. An exhaust system according to any preceding claim, wherein the control means regulates the supply of the NO<sub>x</sub> specific reactant or the precursor thereof in response to pre-determined settings in an engine speed/load map.
16. An exhaust system according to any preceding claim, wherein the control means is arranged to supply the NO<sub>x</sub> specific reactant or the precursor thereof intermittently and at "spike" concentration.

17. An exhaust system according to claim 16, wherein each period between supply of the  $\text{NO}_x$  specific reactant or precursor thereof is selected from the range from 1 second to 10 minutes.
18. A lean-burn internal combustion engine including an exhaust system according to any preceding claim.
19. An engine according to claim 18, wherein it is a diesel engine or a gasoline engine.
20. A process for treating  $\text{NO}_x$  in an exhaust gas from a lean-burn internal combustion engine, which engine including an exhaust system comprising a nitrogen oxide ( $\text{NO}_x$ ) absorbent and a catalyst for catalysing the selective catalytic reduction (SCR) of  $\text{NO}_x$  with a  $\text{NO}_x$  specific reactant wherein the SCR catalyst is disposed upstream of the  $\text{NO}_x$  absorbent and optionally with the  $\text{NO}_x$  absorbent, which process comprising, when the SCR catalyst is below a first pre-determined temperature, contacting the  $\text{NO}_x$  absorbent with insufficient  $\text{NO}_x$  specific reactant to completely reduce the total  $\text{NO}_x$  stored on the  $\text{NO}_x$  absorbent, thereby to regenerate it, and, when the SCR catalyst is above said first pre-determined temperature, contacting it with sufficient  $\text{NO}_x$  specific reactant to reduce  $\text{NO}_x$  in the exhaust gas to  $\text{N}_2$ , whereby exhaustion of  $\text{NO}_x$  specific reactant to atmosphere is substantially prevented.
21. A process according to claim 20, wherein the  $\text{NO}_x$  specific reactant for contacting the  $\text{NO}_x$  absorbent when the SCR catalyst is below the first pre-determined temperature does not contact said catalyst.
22. A process according to claim 20 or 21, wherein, when said SCR catalyst is above said first pre-determined temperature, sufficient  $\text{NO}_x$  specific reactant contacts the SCR catalyst to reduce  $\text{NO}_x$  in the exhaust gas to  $\text{N}_2$  and slips past the SCR catalyst to contact the  $\text{NO}_x$  absorbent thereby to reduce stored  $\text{NO}_x$ , which process is controlled so that the slipped  $\text{NO}_x$  specific reactant is insufficient to completely reduce the total  $\text{NO}_x$  stored.
23. An exhaust system according to claim 20, 21 or 22, wherein the first pre-determined temperature is from 100-600°C, preferably 150-500°C and most preferably 200-450°C.
24. A process according to claim 20, 21, 22 or 23, wherein at the end of regeneration, the  $\text{NO}_x$  absorbent contains 5 to 50% of the content of  $\text{NO}_x$  present at the start of regeneration.

25. A process according to any of claims 20 to 24, wherein regeneration is started when the absorbent contains 5 to 50% of the NO<sub>x</sub> content at which NO<sub>x</sub> slip takes place.
- 5 26. A process according to any of claims 20 to 25, wherein regeneration is controlled to stop at one of the following points:  
when NO<sub>x</sub> specific reactant is detected at a point part-way along the length of a substrate carrying the NO<sub>x</sub> absorbent;  
10 in a system having two substrates carrying the solid absorbent in series, when NO<sub>x</sub> specific reactant is detected at a point between the substrates;  
when a level of NO<sub>x</sub> content prescribed on the basis of pre-determined data in an engine speed/load map has been reached;  
when a level of NO<sub>x</sub> content established iteratively from an initial observation of NO<sub>x</sub>-specific reactant slip has been reached.
- 15 27. A process according to any of claims 20 to 26, wherein the time period of absorption and/or regeneration is in the range of from 1 second to 10 minutes.
- 20 28. A process according to any of claims 20 to 27, wherein the NO<sub>x</sub> absorbent is supported on a first substrate and the SCR catalyst is supported on a second substrate.
- 25 29. A process according to any of claims 20 to 28, wherein the NO<sub>x</sub> specific reactant is produced *in situ* from a precursor thereof.
- 30 30. A process according to claim 29, further including a step of catalytically reacting the precursor to provide NO<sub>x</sub> specific reactant.
31. A process according to any of claims 20 to 30, wherein the starting gas is the exhaust of a lean-burn, especially diesel, internal combustion engine.
32. A process according to claim 31, wherein the engine burns fuel of less than 10 ppm sulfur.

## ABSTRACT

**EXHAUST SYSTEM FOR LEAN BURN IC ENGINES**

5  
10  
15  
An exhaust system (10) for a lean-burn internal combustion engine comprises a nitrogen oxide ( $\text{NO}_x$ ) absorbent (28), a catalyst (30) for catalysing the selective catalytic reduction (SCR) of  $\text{NO}_x$  with a  $\text{NO}_x$  specific reactant, first means (18, 22) for introducing a  $\text{NO}_x$  specific reactant or a precursor thereof into an exhaust gas upstream of the SCR catalyst (30) and means (24) for controlling the introduction of the  $\text{NO}_x$  specific reactant or precursor thereof into the exhaust gas via the first introducing means (18, 22), wherein the SCR catalyst (30) is disposed upstream of the  $\text{NO}_x$  absorbent (28) and optionally with the  $\text{NO}_x$  absorbent, characterised in that the control means (24) is arranged to supply the  $\text{NO}_x$  specific reactant or the precursor thereof to the first introducing means (18, 22) only when the SCR catalyst (30) is above a first pre-determined temperature, whereby exhaustion of  $\text{NO}_x$  specific reactant to atmosphere is substantially prevented.

20 [Figure 1]



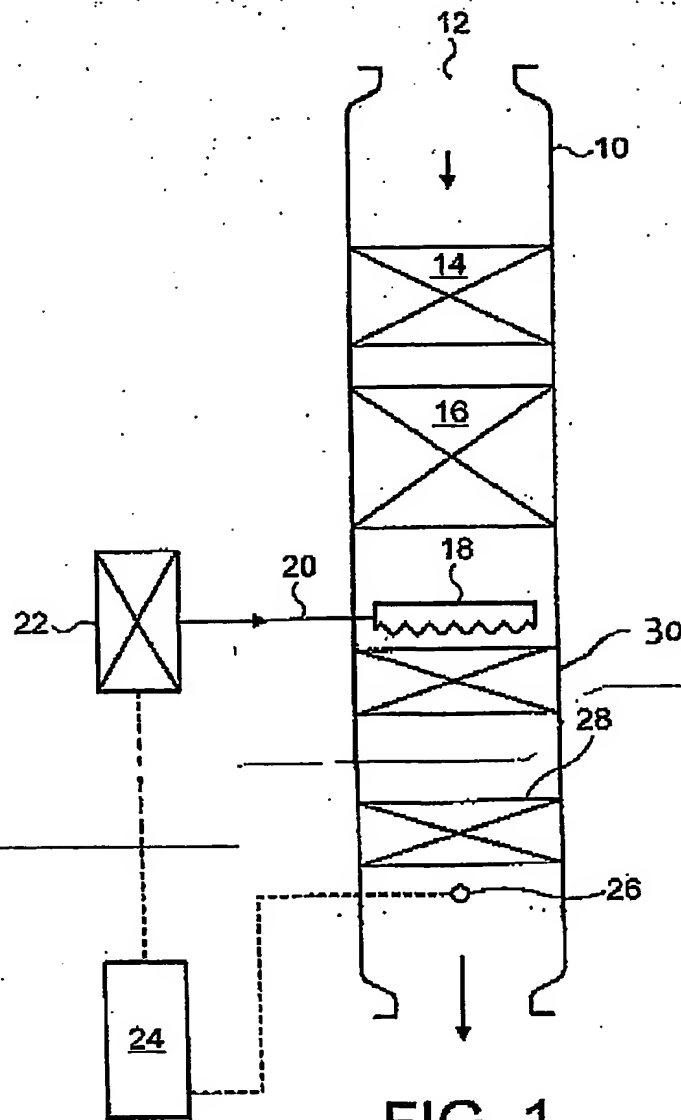


FIG. 1

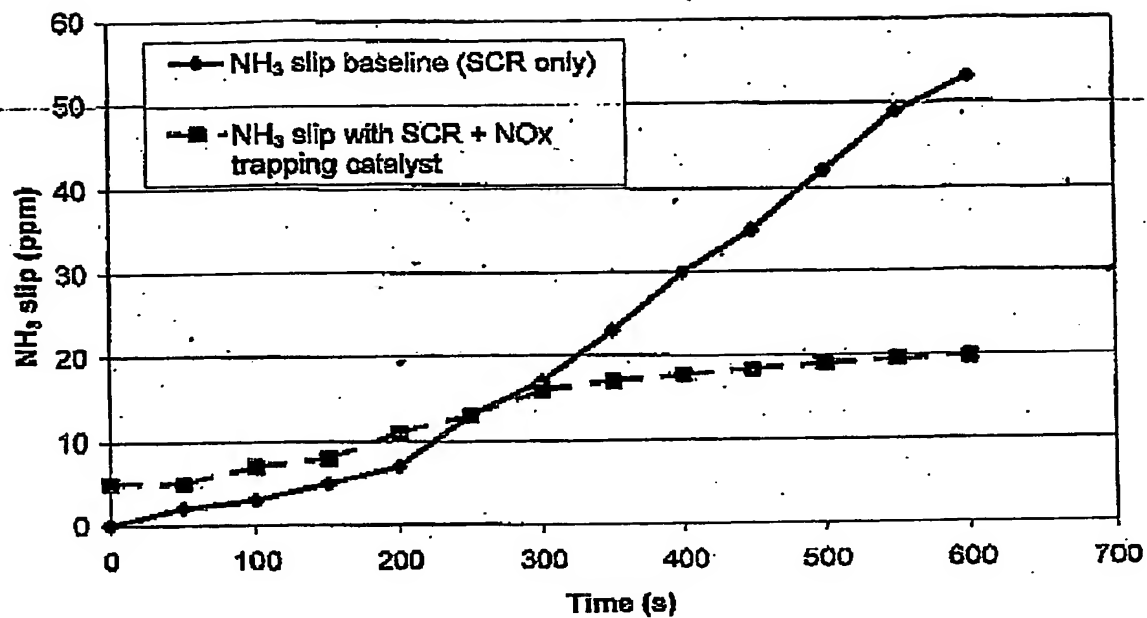


Figure 2

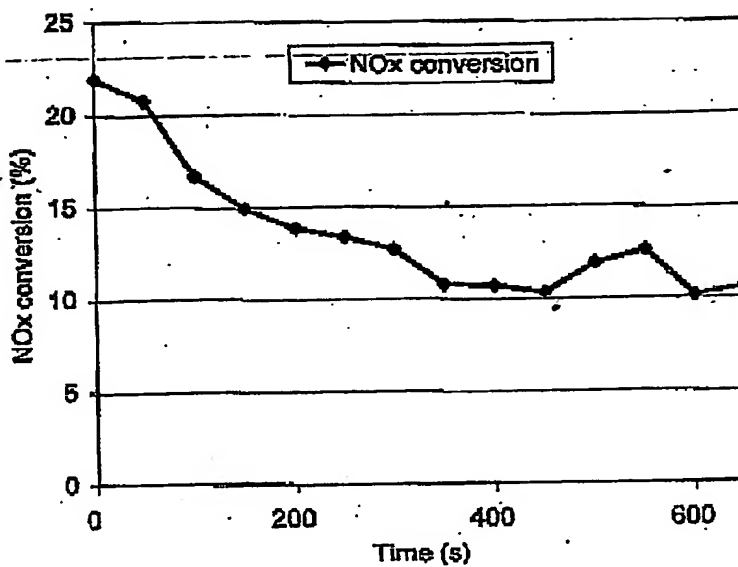


Figure 3

PCT Application  
**GB0303827**



**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☒ **BLACK BORDERS**
- ☒ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☒ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☒ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**